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6. AUTHOR(S)
Alan C. Bovik

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Texas at Austin

Dept of ECE
24th and Speedway
Austin, Texas 78712

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Our research has focussed on the application of recently-developed AM-FM models to practical problems in image processing and analysis. We have been emphasizing three directions:

(1) FM-Based Image Compresssion
(2) Multicomponent AM-FM Signal Representations
(3) AM-FM Image Synthesis Using Reaction-Diffusion Equations.

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AM-FM ANALYSIS OF IMAGES AND VIDEO

(Final Report)

Professor Al Bovik
The University of Texas at Austin
Austin, Texas 78712
bovik@ece.utexas.edu

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Status of Effort

Our research has focussed on the application of recently-developed AM-FM models to practical problems in image processing and analysis. We have been emphasizing three directions:

(1) FM-Based Image Compresssion
(2) Multicomponent AM-FM Signal Representations
(3) AM-FM Image Synthesis Using Reaction-Diffusion Equations.

Our progress in these directions is detailed in the following.

(1) FM-Based Image Compresssion
(J. Havlicek, A. Bovik)

Our work has concentrated on the study of discrete FM transformsfor use in image compression. The general discrete FM transform takes has the same form as a DFT, only the arguments of the sinusoidal basis functions are nonlinear. Hence, they are FM functions. We have proven that the only orthogonal FM transforms are in fact permutation transforms. These can be interpreted as DFT's, where the basis function time indices are permuted, or alternately (and equivalently) the input signal is first permuted prior to making the frequency transformation. This implies that optimal FM transforms can be sought that optimally concentrate the spectral energy of the signal via a time-domain permutation. Extremely high compression of the permuted signal can be obtained, but this is balanced by the overhead in storing the permutation itself (so that the FM transform can be inverted).

In our studies we have developed a new signal/image codec named COPERM [1], which is a particularly efficient paradigm for broadband signal compression. The foundation of COPERM is a simple but powerful idea: any signal can be transformed to resemble a more desirable signal (such as one that is spectrally concentrated, such as a sinusoid) by means of a suitable permutation. We have developed basic theoretical results and associated fast computational algorithms. We have designed a fully functional image codec that touches on the rate-distortion performance of JPEG, while treating the image as one-dimensional data. The approach is well-suited to transform-domain compression, but is very generic. In addition, we have extended these concepts in an unusual way into

higher-dimensional AM-FM transforms, resulting in improved approaches for lossless image compression [2]

[1] N. Sidiropoulos, M.S. Pattichis, A.C. Bovik and J.W. Havlicek, "COPERM: Transform-domain energy compaction by optimal permutation," *IEEE Transactions on Signal Processing,* vol. 47, no. 6, pp. 1679-1688, June 1999.

[2] M.S. Pattichis, A.C. Bovik, J.W. Havlicek and N.D. Sidiropoulos, "Multidimensional orthogonal FM transforms," *IEEE Transactions on Image Processing*, to appear.

(2) Multicomponent AM-FM Signal Representations
(J. Havlicek, D. Harding, J. Wehnes, and A. Bovik)

We are designing algorithms for computing multicomponent AM-FM representations of multidimensional signals. Under the multicomponent AM-FM model, at each point, a signal may be composed of many AM-FM components. The model parameters for each of these components may be estimated by narrow-band spatio-spectral filtering applied at each point followed by the application of an energy separation algorithm such as those that we developed under the expired parent AFOSR grant, "Local Spatiotemporal Analysis of Vision Systems." In our previous work, AM-FM image components were assumed to vary smoothly across the regions of support. To separate the components present at each point, we have previously used a Kalman filter-based component tracking paradigm [3]-[5]. While this approach has met with some successes, it is unable to deal with image that contain multiple objects, separated by sudden boundaries, with different texture characteristics within each boundary.

We are attempting to generalize our approach via a global "preprocessing" of the signal/image in order to identify and separate suitable AM-FM components before they are estimated. This promises to avoid the problems inherent in any tracking algorithm which operates by progressing along spatial coordinates which is difficult to accomplish in higher than one dimension. Our current design involves first applying a space-frequency transform (the discrete gabor transform) on the signal/image to be modeled. This transform reveals local frequency structure in different regions of the image, including across textural boundaries. The next step in the preprocessing algorithm is to identify the components based on continuity detection along maximal-response contours across the spatial-frequency surface. Once identified, each component is isolated by a space-varying filter designed to capture only its energy. This filtering occurs in the space-frequency transform domain. Each isolated component is then individually inverse-transformed back to the spatial domain. At this point, the AM-FM modulation functions for each component can be estimated by direct application of the energy separation algorithm, yielding an accurate, global, multi-object, multicomponent AM-FM representation of the image. The main challenge that we are currently tackling involves the estimation of peak locations on the Gabor energy surface.

[3] J.P. Havlicek, D.S. Harding and A.C. Bovik, “The multicomponent AM-FM image representation,” *IEEE Transactions on Image Processing,* Special Issue on Nonlinear Image Processing, vol. 6, no. 5, pp. 1094-1100, June 1996.

[4] J.P. Havlicek, D.S. Harding and A.C. Bovik, "Multicomponent multidimensional signals," *Multidimensional Systems and Signal Processing,* vol. 9, pp. 391-398, 1998.

[5] J.P. Havlicek, D.S. Harding and A.C. Bovik, "Multidimensional quasi-eigenfunction approximations and multicomponent AM-FM models," *IEEE Transactions on Image Processing,* vol. 9, no. 2, pp. 227-242, February 2000.

(3) AM-FM Image Synthesis Using Reaction-Diffusion Equations
(S. Acton, J. Havlicek and A. Bovik)

This has been a speculative but productive aspect of our AM-FM research. It is known that the solutions of certain reaction-diffusion PDE's are AM-FM functions. This suggests a difficult inverse problem: be estimating the appropriate reaction-diffusion parameters of a given texture, generate other realizations of this texture by numerically solving the RD PDE's. Our results in this direction have been rather successful given the extreme difficulty of the problem: as noted by R. Picard of MIT, the inverse solution of RD-PDE's is an extremely ill-posed problem compounded by the extreme noise sensitivity of the reaction components. In our approach, we estimate the RD parameters by conducting an AM-FM decomposition of a sample image, then seed the texture to be generated using random noise. The solution to the RD PDE is then regularized by imposing a locally bandpass constraint that is determined from the AM-FM estimate. Ideally, numerical iterations should then yield a reasonable texture synthesis. Unfortunately, the success of the approach appears to be contingent upon the imposition of appropriate boundary conditions which are difficult to obtain.

We have recently been able to obtain significant success in applications where there are natural boundary conditions available [6]. Such a situation occurs when a natural texture has a region missing; estimation of the texture in the missing region can be accomplished by establishing the boundary conditions at the region periphery, using the known texture at these points as the boundary condition. In this case, the iterations converge nicely to very realistic and reasonable texture syntheses. In our experiments, we have been using fingerprint images with both naturally missing regions and artificially removed regions. The solutions that we are obtaining in these cases are very realistic, and easily mistaken for actual fingerprints. We envision the technique to be immediately useful for "fingerprint completion" when part of a print is missing. This has application not for identification, since local bifurcations in the solution of the RD-PDE lead to different fingerprint minutiae, but rather, for classification, where the entire flow pattern is needed to classify the fingerprint by type.

[6] S.T. Acton, D.P. Mukherjee, J.P. Havlicek and A.C. Bovik, “Oriented texture completion by AM-FM reaction-diffusion," *IEEE Transactions on Image Processing*, to appear.